Sara Ventura*
Instituto Polibienestar
University of Valencia
Spain

Department of Psychology
University of Bologna
Bologna, Italy

Alessia Tessari
Department of Psychology
University of Bologna
Bologna, Italy

Alma Mater Research Institute for
Human-Centered Artificial
Intelligence
University of Bologna
Bologna, Italy

Do Object Affordances Modulate the Sense of Embodiment in Virtual Human–Tool Interaction? Reflection for the Interactive Artificial Environment

Abstract

Object manipulation is essential to build the surrounding reality, and affordances—the action possibilities offered by the environment—have a crucial role in human–tool interaction. Due to the exponential growth of the metaverse, a research question arises: Does the theoretical model behind the human–tool interaction also work in artificial reality? The present study aimed to investigate the difference in the sense of embodiment in human–tool interaction between usual and unusual objects in an immersive 360-degree video. The environment is a recording of a human arm that interacts with various tools on a table. Forty-four participants took part in the study, and they were randomized into two groups, usual or unusual objects, and in two within-participants conditions, reach to move or reach to use. Results showed no significant difference in the embodiment between usual and unusual objects, demonstrating that the ventral and dorsal streams may perfectly integrate information in the artificial environment as in the real world. Participants felt present in the virtual environment, as demonstrated by the factor location of embodiment, so they believed they could interact with any tools, independently of their affordances. The study contributes to understanding the mechanisms behind human–tool interaction in the artificial environment.

1 Introduction

Object manipulation is essential to designing our surrounding reality, despite influencing the movements in space. The manipulation of objects requires an interdependence between the visual and motor systems expressed by the direct and immediate link between the perception of the object and the potential actions an agent can perform on that object (Johansson et al., 2001). The action possibilities that are readily perceivable by an actor have been defined as "affordances" and are based on the relationships among an object, its environment, and the observer/actor. According to Gibson (1977), given species evolved in a certain ecological niche—the environment directly offers them the possibility to perceive it correctly without the mediation of mental representations—and humans tend to modify their environment to change its affordances

Presence, *Vol. 30, Winter 2021*, 203–212
https://doi.org/10.1162/PRES_a_00382

---

*Correspondence to sara.ventura@uv.es.

to suit them better (Jones, 2018). Affordances can be distinguished as stable or variable: stable refers to the invariant properties of the objects, which are independent from the relationship with the agent who interacts with them (e.g., the dimension or weight); variable affordances refer to the temporary properties of the objects' characteristics linked to the actions to be performed on them (e.g., the location of the object or its orientation) (Borghi & Riggio, 2015).

The human agent processes the different affordances through the anatomical Two-Action Systems (2AS), ventro-dorsal and dorso-dorsal streams, respectively, that operate independently and in parallel, allowing the agent to integrate them to act (Buxbaum & Kalénine, 2010). Specifically, the ventro-dorsal stream system focuses on the functional aspects of manipulating objects, and relates to the agent's prior sensorimotor knowledge about the object use. The dorso-dorsal stream focuses on manipulating the object according to the visual properties and is constantly updated during the action (Binkofski & Buxbaum, 2013). The 2AS was adopted as a guideline to understand and explain the embodied cognition paradigm, which claims that cognitive processes are simply simulations of previously acquired sensorimotor experiences. In fact, the brain creates multisensory simulations to predict an action that is a result of the integration of sensory experiences from both inside (agent's previous experience) and outside (agent's social context) the body (Friston et al., 2010). For example, when we see a pen on a table, the ventro-dorsal stream reminds us how to reach and adjust our pinch to grasp the pen, while the dorso-dorsal stream brings to our mind what to use it for—to sign a document, for example. This was reflected in a study that examined the participants' response time difference in the interaction with usual and unusual objects, demonstrating how the elaboration of the unusual objects is longer than the usual ones (Sciulli et al., 2018).

In recent years, we have assisted in the exponential growth of the simulative environment, the so-called "metaverse," a mixed reality between real and artificial environments. The word metaverse was first introduced by Neal Stephenson in 1992 in his novel *Snow Crash.* He defined metaverse as a massive virtual environment that can expand the physical world and enable users to seamlessly engage with both real and simulated environments through avatars and holograms (Joshua, 2017). Since their first appearance, the technologies to allow the creation of the metaverse are fast evolving with the use of VR headsets, haptic gloves, Augmented Reality, and Extended Reality, which enable users to fully experience high levels of interaction and immersive experience (Li et al., 2019; Lee et al., 2021; Dwivedi et al., 2022). The technology's evolution has generated a difference between the metaverse described by Neal Stephenson and the one that tech companies are working on. The main feature of the new metaverse is its "interreality"(Riva et al., 2010), namely the fusion between the virtual world and the physical one. For example, Meta Platforms are working on the potentialities of the metaverse to shape many aspects of how we work and socialize (Buana et al., 2023).

In this new social dimension, virtual and real objects coexist in the same place, and what we do in the physical world influences the experience in the virtual world and vice versa (Riva & Wiederhold, 2022). Previous studies stated that virtual components have to follow physical laws (Steffen et al., 2019), meaning that the artificial environment should reflect realistic interaction and should reproduce the real sensation of touching and moving objects to generate a high sense of immersion (Gross et al., 2005; Sait et al., 2018). However, how people interact with different objects, both usual and unusual, in a synthetic environment is still less investigated.

Among the immersive technologies adopted in psychological research (Suh & Prophet, 2018), the 360-degree video has grown exponentially. This technology consists of video recordings shot using omnidirectional cameras or a collection of synchronized cameras with overlapped field of view that allows users to see the environment all around them. Moreover, through the head-mounted display, it is possible to reproduce the real environment in a second time and generate an immersive experience for participants (Huang et al., 2017; Repetto et al., 2018; Ventura, Miragall, et al., 2022; O'Meara, 2021). The missing feature that prevents the 360-degree video from being completely VR is the interaction with the virtual environment; that is, users are only passive observers of the virtual experience, but they cannot interact with it (Boeck et al., 2006). However, it has been demonstrated that the 360-degree video is an efficacious instrument to elicit the body swap illusion (Ventura, Cebolla, et al., 2022) and, considering the cost-efficacy of the technology, it was adopted in literature to study how the mechanism of changing perspective from one person to another could impact prosocial behavior and attitude change (Kool, 2016; Ventura et al., 2021; Sansoni et al., 2022).

In the present study, we adopted the paradigm of the body illusion to understand how participants experience the interaction and the manipulation of virtual objects and the different affordances characterizing them. The sense of embodiment is the perception of one's body given agency, ownership, and location (Lenggenhager et al., 2007). This body perception can be altered in VR by eliciting the body swap illusion, inducing the participants to perceive themselves with a different body. To this end, the present study investigates the difference in participants' body swap illusion while interacting with usual or unusual objects in an immersive 360-degree video.

2 Method

2.1 Participants

Forty-four participants, 31 (70.5%) of which were women, with an average age of 23.52 years (SD = 3.33), participated in the study. Potential participants were recruited through word of mouth at the University of Bologna, Italy. Only those who were at least 18 years old and reported not having physical problems that could inhibit free movements were included in the study. Sample characteristics are summarized in Table 1.

2.2 Ethical Statement

The study was approved by the Ethics Committees of the University of Bologna (UNIBO, protocol number: 142333).

Table 1. *Sample Characteristics*

	M (*SD*)	%
Age	23.52 (3.33)	–
Educational level		
Secondary studies	–	36.4%
Degree	–	56.8%
Masters	–	6.8%
Dominant hand		
Right	–	95.5%
Left	–	4.5%
Interoceptive Awareness (MAIA)		
Noticing	4.44 (1.02)	–
Not-Distracting	1.60 (0.88)	–
Not-Worrying	2.25 (0.77)	–
Attention Regulation	4.09 (1.05)	–
Emotional Awareness	4.23 (1.28)	–
Self-Regulation	3.57 (1.13)	–
Body Listening	3.56 (1.17)	–
Trusting	4.39 (1.22)	–
Mechanical reasoning test		
Accuracy	0.73 (0.25)	–
Time employed	1’23” (0.50”)	–

2.3 Measures

Participants were invited to respond to the following questionnaires:

Sociodemographic: an ad-hoc questionnaire containing 4 items that collects information about age, sex, education level, and the dominant hand.

Sense of embodiment: a self-report questionnaire with 12 items rated on a 7-point scale (1 = strongly disagree; 7 = strongly agree) adapted from Longo's original questionnaire to assess the ownership, location, and agency of the virtual body (Longo et al., 2008) ($\alpha = .723$).

Multidimensional Assessment of Interoceptive Awareness (MAIA): an Italian-validated self-report questionnaire with 32 items rated on a 6-point scale (0 = never; 5 = always), which measures the interoceptive awareness of participants' bodies (Calì et al., 2015). It comprises eight factors: *Noticing* refers to the awareness of unpleasant, pleasant, and neutral body sensations. *Not-Distracting* refers to the tendency not to ignore or be distracted by feelings of pain or discomfort; *Not-Worrying* refers to the tendency not to care or experience emotional distress in the presence of feelings of pain or discomfort; *Attention Regulation* refers to the ability to sustain and control attention to bodily sensations; *Emotional Awareness* refers to the awareness of the connection between bodily sensations and emotional states; *Self-Regulation* refers to the ability to regulate emotional distress by paying attention to bodily sensations; *Body Listening* refers to the active listening to the body for insight; *Trusting* refers to viewing one's own body as safe and reliable. The α of the present study is .629.

Rating stimulus: an ad-hoc questionnaire that contains 12 items rated on a 5-point scale (1 = strongly agree; 5 = strongly disagree) which evaluates the participants' familiarity and comfort with the stimulus presented (e.g., "Do you think this key will enable you to open the lock? Do you think this cup allows you to drink?").

Mechanical reasoning test: an ad-hoc test with 3 reasoning tests based on gear rotation rate with *correct* (score = 1) and *incorrect* (score = 0), and the time required by participants to resolve the test. It evaluates the participants' response to mental simulation (Hegarty, 2004).

2.4 The 360° Video and the Objects Presented

The 360-degree video was recorded with the LG360-105 camera and played by the Oculus Rift (head-mounted display) connected to the Dell Alienware 15 R4 Computer (Intel® Core$^{\text{TM}}$ i7 12700H; 16 GB, LPDDR5, 5.200 MHz; Graphic Processing Unit: NVIDIA® GeForce RTX$^{\text{TM}}$ 3060). The camera was attached to the performer's head with proper support to create the first-person perspective. This mechanism was already tested in previous work to elicit the first-person perspective body illusion (Ventura, Cebolla, et al., 2022). The recording was led by both a female and a male performer to ensure the body illusion of all participants (Petkova & Ehrsson, 2008).

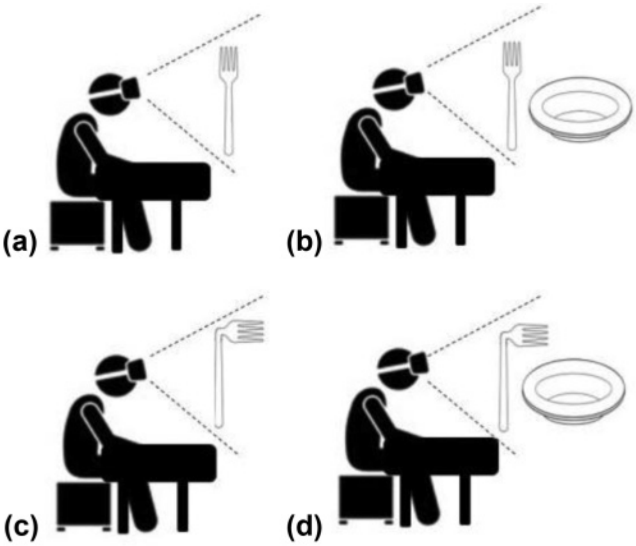

Figure 1. *The upper panel represents the comfortable conditions, and the lower panel represents the uncomfortable conditions. In panels (a) and (c), the objects are contextualized; in panels (b) and (d), the objects are out of context. Study conditions and counterbalanced design.*

The recorded environment had two parts: first, the induction of body illusion, where participants were invited to follow the prerecorded body movements of the performers for approximately three minutes. This task aimed to facilitate the participants' body illusion with the virtual performer. Second, the participants were invited to follow the performer's interaction with usual and unusual objects[1] in a dual condition: contextualized and out-of-context objects (see Figure 1). The difference between usual and unusual objects relates to the objects' affordances; for example, the affordances of the unusual objects make the tools difficult to use, as the participants could find a divergence between the common functionality and the appearance of the actual object (see Figure 2).

2.5 Procedure

The experiment took place at the Department of Psychology, University of Bologna. After signing the

---

[1] The idea originated from the artistic project "The Uncomfortable" by Katerina Kamprani (https://www.theuncomfortable.com/).

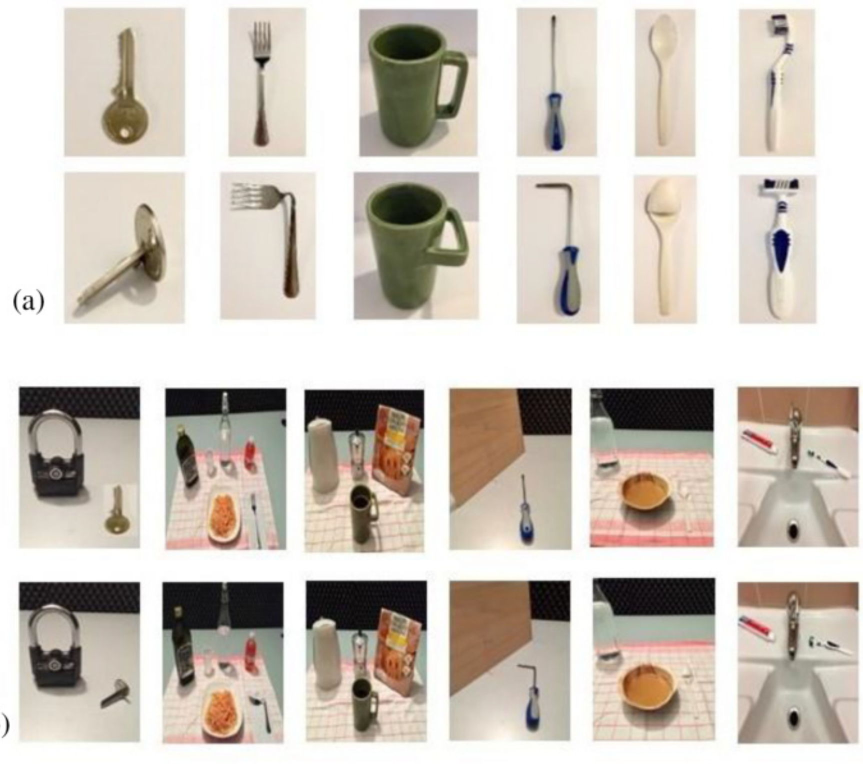

Figure 2. *Stimuli presented to participants: (starting from left) key, fork, cup, screwdriver, spoon, toothbrush. Panel (a) presents both usual and unusual stimuli out of context and placed on a table; panel (b) presents the same stimuli contextualized to reflect the action that the agent can do with each stimulus.*

informed consent, participants were randomized in two conditions—interaction with usual and unusual objects—and counterbalanced in two further conditions—reach-to-use (contextualized) and reach-to-move (out-of-context) (see Figure 3). Then, they were invited to complete the demographic questionnaire, rate the test stimuli to evaluate their familiarity with the presented objects, and start the experiment. During the experimental task, they were invited to sit on a chair and wear the Oculus to interact with the virtual objects. The 360-degree video was structured in two sessions, reach-to-use (contextualized) and reach-to-move (out-of-context). After each session, participants verbally answered the sense of embodiment questionnaire while wearing the Oculus and the researcher read them the items. At the end of the 360-degree video, participants again completed the sense of embodiment test and were asked to solve the mechanical reasoning test.

3 Results

3.1 Rating Stimulus

Table 2 shows results on the participants' familiarity with the stimuli, namely the knowledge and ability to use the tools in daily life activities. Results showed a significantly higher score for usual than unusual objects.

3.2 The Differences in the Sense of Embodiment Between Usual and Unusual Objects

A one-sample t-test indicated no significant difference in embodiment between interaction with usual and unusual objects (see Table 3).

To better explore the absence of significant differences between usual and unusual conditions in all three

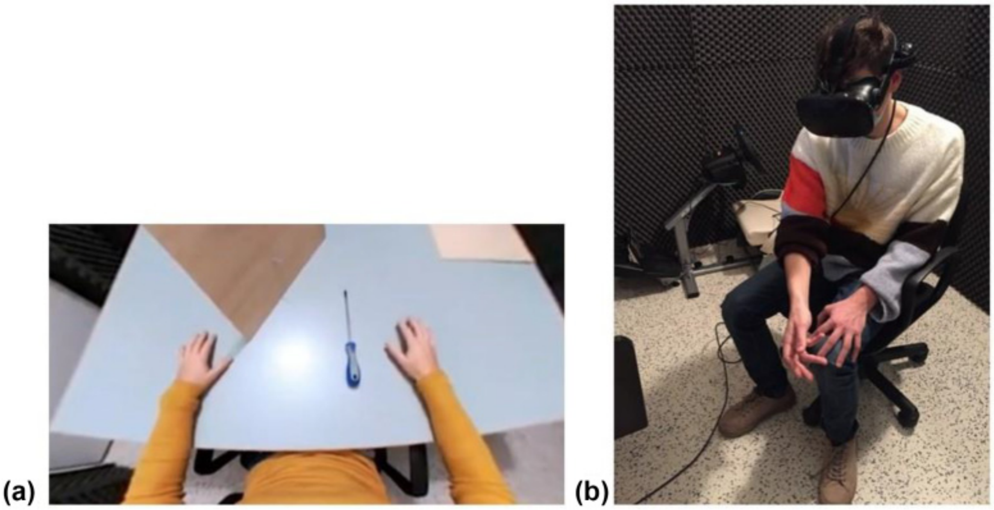

Figure 3. *Figure 3a represents a screenshot of the 360-degree video content frame from the participant's perspective. Figure 3b shows a participant during the experiment session.*

Table 2. *Results of Rating Stimuli*

	Usual		Unusual		Paired *t*-test		
Stimuli	Mean	SD	Mean	SD	*t*	*p*	*d*
Key	1.55	0.94	2.98	0.95	(41) = −6.87	<0.01	1.51
Fork	1.05	0.21	2.64	1.00	(41) = −9.96	<0.01	2.20
Cup	1.10	0.29	1.67	0.81	(41) = −4.46	<0.01	0.94
Screwdriver	1.14	0.35	2.24	1.14	(41) = −6.21	<0.01	1.30
Spoon	1.24	0.48	4.07	0.81	(41) = −20.84	<0.01	4.25
Toothbrush	1.07	0.26	2.93	1.10	(41) = −10.38	<0.01	2.33

Table 3. *Descriptive Statistics and Bayesian Paired Samples t-Test of the Three Subscales of the Embodiment Questionnaire Within the Two Conditions (Comfortable and Uncomfortable) (N = 44)*

	Usual		Unusual		Comparison		
Description	Mean	SD	Mean	SD	BF[a]	Error percent	Effect
Ownership	3.46	1.30	3.88	1.11	6.40	∼3.297e-4	Strong
Agency	2.90	1.31	3.41	1.36	6.70	∼2.258e-4	Strong
Location	4.77	1.49	5.38	1.31	7.26	∼9.820e-5	Strong

NOTE. [a] Evidence in favor of the model of interest (similarity of measures) is considered anecdotal ($1 < \mathrm{BF} < 2.5$) or strong ($2.5 < \mathrm{BF} < 10$). To compare the relative predictive success of one model over another, the BF of the first model was divided by the BF of the other model, and the value of this ratio was interpreted in terms of the strength of evidence using the same values as above.

BF: Bayes factor.

Table 4. *Results of Multiple Regression Analysis*

Outcomes	Predictors	R	Adjusted R^2	R^2 Change	B	SE	β	t
Ownership	Constant				5.22	5.13		10.17
	Mechanical reasoning	.44	.18	.20	−2.10	0.66	−.44	-3.18^{**}
Agency	Constant				4.49	5.95		7.54
	Mechanical reasoning	.34	.10	.12	−1.81	0.77	−.34	-2.36^{*}

$^{*}p < 0.05$; $^{**}p < 0.01$.

embodiment dimensions—ownership, agency, and location—we used the paired sample t-test Bayes Factor (BF_{01}) to assess a ratio between the likelihood of the data given the null hypothesis (no difference between conditions) and the one given by the alternative one (group 1 > group 2). Evidence showed a strong effect for the three factors of embodiment—ownership ($\mathrm{BF}_{01} = 6.40$), agency ($\mathrm{BF}_{01} = 6.70$), and location ($\mathrm{BF}_{01} = 7.26$)—highlighting that the three embodiment factors are statistically similar in the two conditions (usual and unusual objects), in contrast to the hypotheses that they are different. Thus, overall, participants reported that they felt located in the virtual environment in both conditions.

3.3 Mechanical Reasoning Ability as a Predictor of the Sense of Embodiment

The stepwise multiple regression of embodiment score demonstrated that the ownership factor is negatively predicted by the participants' ability in the mechanical reasoning test: this model was statistically significant, $F(1, 43) = 10.15$, $p < 0.05$, $R^2 = 0.20$, explaining 20% of the variance (see Table 4). The second multiple regressions to predict agency showed that the participants' ability in the mechanical reasoning test is a negative predictor. The model was statistically significant, $F(1, 43) = 5.56$, $p = 0.01$, $R^2 = .12$, explaining 12% of the variance. The factor location did not enter into the model.

4 Discussion

The present study aimed to investigate the difference in participants' interaction between usual and unusual objects in an immersive environment. Given the exponential growth of the metaverse and the impact that it will have on social interaction (Riva & Wiederhold, 2022; Dwivedi et al., 2022), it is essential to understand the human–tool interplay in the virtual world, including the interaction with usual and unusual objects. Interacting with objects in Virtual Reality (VR) can be a very immersive and intuitive experience, allowing the participant to perceive the environment as natural and familiar (Slater & Wilbur, 1997). Moreover, it can be used for a wide range of applications, including gaming, education, training, and medical rehabilitation (Sait et al., 2018).

During the human–tool interaction, a specific brain network, comprehending the ventro-dorsal and dorso-dorsal streams, processes objects' affordances and the associated actions (Buxbaum, 2017). The ventro-dorsal stream processes sensorimotor information based upon longer-term object use representations (their function), and the dorso-dorsal stream controls online actions based on currently visible structure of objects (Binkofski & Buxbaum, 2013). For example, in our study, if the participants interacted with the fork, the ventro-dorsal stream would help them to recognize that it was a fork and its function through its shape and size, while the dorso-dorsal stream would help in controlling the action online based on variable affordances. Previous work investigated how the ventro-dorsal and dorso-dorsal streams are involved in the interaction with unusual objects: interaction with them is slower than the interaction with the usual ones because they may require more effort to be executed (Sciulli et al., 2018). Thus, how does the Two-Actions System operate in the synthetic environment? To answer this question, we adopted the paradigm of the body illusion to investigate if there is a difference in participants' body illusion while interacting with usual and unusual objects in a 360-video-based VR.

First of all, the study confirmed previous work that the 360-degree video can elicit the body ownership illusion (Ventura, Cebolla, et al., 2022). Furthermore, we found no significant difference in the sense of embodiment between interaction with usual and unusual objects, despite the significant difference in participants' familiarity with the two types of objects. Indeed, participants recognized their difficulty in using unusual tools in daily life. Previous study on the sense of presence and the interaction with objects showed that how participants perform the VR task using real objects is more similar to how they would do it in a real environment (Lok et al., 2003). The Bayesian analysis reinforced the results, confirming that the two conditions are statistically similar (Masson, 2011). According to our results, participants' interaction with usual and unusual objects was equally immersive and induced a similar body illusion experience, independent of the objects' affordances. This is an interesting result because it could pave the way for both streams, the ventro-dorsal and the dorso-dorsal, to work at the same level and interact in the virtual environment.

An interesting result emerged when analyzing the relationship between mechanical reasoning abilities and the embodiment dimensions. The ability to perform the mechanical reasoning test negatively predicts the dimensions of the sense of ownership and agency. Mechanical reasoning is involved in understanding how objects and the engineering system work and helps to analyze and solve mechanical problems (Christensen & Schunn, 2009). We can hypothesize that the ability in mechanical reasoning may facilitate the participant to interact with unusual objects as they specifically require thinking creatively to understand if the perceived affordances suit the intended action with that object, e.g., how to grip or hold the object, how to apply force to it, or how to use it in a particular way (Osiurak et al., 2009). Both mechanical reasoning and object interaction tasks involve the mental simulation of the expected perceptual effect on tool use. In our study, participants who had good ability to solve the mechanical reasoning demonstrated their tendency to critically reflect and examine objects' features—for example, what is the object, how to use or manipulate it, etc. (Boucinha et al., 2019)—which may have induced the participants to disembody the virtual performer as they were more focused on the experimental task and the proprioception of their own real body over the virtual one. On the contrary, participants who demonstrated less skill in the mechanical reasoning test maintained the body illusion with the virtual performer for the entire experiment.

This study presents different limitations. First, the sample size was small and homogeneous; most participants were university students with a low variance in age. Replication studies in larger community samples are required. Second, the technology adopted to induce the body swap illusion presented some weaknesses. The virtual environment was a 360-degree prerecorded video, so participants simply followed the performer's movements and were not free to navigate and explore the environment independently. It would be interesting in future studies to use the suit body track that allows the participant to interact with the virtual objects and use them as they like. Regarding the methodological limitations, we administered only self-report questionnaires. In a follow-up study, we plan to collect kinematic data and adopt a dynamometer to evaluate the reaching and grasping participants' activities while interacting with different objects (and affordances) in VR. This method may increase the measure's reliability of the participant–tool interaction.

Despite its limitations, the present study paves the way to understanding the mechanism behind the human–tool interaction in the synthetic environment, which could be different than the real one. As the main feature of the metaverse is, in fact, its "interreality"—the fusion between the virtual world and the physical one (Riva & Wiederhold, 2022)—investigating the users' embodied ability is crucial for the development of bidirectional realities.

Acknowledgments

This work was funded by a Margarita Sala postdoctoral fellowship for the requalification of the Spanish university system from the Ministry of Universities of the Government of Spain and financed by the European Union NextGeneration EU (grant UP2021-044).

REFERENCES

Binkofski, F., & Buxbaum, L. J. (2013). Two action systems in the human brain. *Brain and Language*, *127*(2), 222–229. 10.1016/j.bandl.2012.07.007

Boeck, J. D., Raymaekers, C., & Coninx, K. (2006). Exploiting proprioception to improve haptic interaction in a virtual environment. *Presence: Teleoperators and Virtual Environments*, *15*(6), 627–636. 10.1162/pres.15.6.627

Borghi, A. M., & Riggio, L. (2015). Stable and variable affordances are both automatic and flexible. *Frontiers in Human Neuroscience*, *9*, 351. 10.3389/fnhum.2015.00351

Boucinha, R. M., Barone, D. A. C., Reichert, J. T., Brackmann, C. P., & Schneider, A. M. (2019). Relationship between the learning of computational thinking and the development of reasoning. *International Journal of Advanced Engineering Research and Science*, *6*(6), 623–631. 10.22161/ijaers.6.6.71

Buana, M. W. (2023). Metaverse: Threat or opportunity for our social world? *Journal of Metaverse*, *3*(1), 28–33.

Buxbaum, L. J., & Kalénine, S. (2010). Action knowledge, visuomotor activation, and embodiment in the two action systems. *Annals of the New York Academy of Sciences*, *1191*(1), 201–218. 10.1111/j.1749-6632.2010.05447.x

Calì, G., Ambrosini, E., Picconi, L., Mehling, W., & Committeri, G. (2015). Investigating the relationship between interoceptive accuracy, interoceptive awareness, and emotional susceptibility. *Frontiers in Psychology*, *6*, 1202.

Christensen, B. T., & Schunn, C. D. (2009). The role and impact of mental simulation in design. *Applied Cognitive Psychology*, *23*(3), 327–344.

Dwivedi, Y. K., Hughes, L., Baabdullah, A. M., Ribeiro-Navarrete, S., Giannakis, M., Al-Debei, M. M., . . . & Wamba, S. F. (2022). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, *66*, 102542. 10.1016/j.ijinfomgt.2022.102542

Friston, K. J., Daunizeau, J., Kilner, J., & Kiebel, S. J. (2010). Action and behavior: A free-energy formulation. *Biological Cybernetics*, *102*(3), 227–260. 10.1007/s00422-010-0364-z

Gibson, J. J. (1977). *The theory of affordances*. Erlbaum Associates.

Gross, D. C., Stanney, K. M., & Cohn, L. J. (2005). Evoking affordances in virtual environments via sensory-stimuli substitution. *Presence: Teleoperators & Virtual Environments*, *14*(4), 482–491.

Hegarty, M. (2004). Mechanical reasoning by mental simulation. *Trends in Cognitive Sciences*, *8*(6), 280–285. 10.1016/j.tics.2004.04.001

Huang, J., Chen, Z., Ceylan, D., & Jin, H. (2017). 6-DOF VR videos with a single 360-camera. In *2017 IEEE Virtual Reality (VR)*, pp. 37–44.

Johansson, R. S., Westling, G., Bäckström, A., & Flanagan, J. R. (2001). Eye–hand coordination in object manipulation. *Journal of Neuroscience*, *21*(17), 6917–6932. 10.1523/JNEUROSCI.21-17-06917.2001

Jones, K. S. (Ed.). (2018). How Shall Affordances Be Refined?: Four Perspectives: A Special Issue of Ecological Psychology. Psychology Press.

Joshua, J. (2017). Information bodies: Computational anxiety in Neal Stephenson's *Snow Crash*. *Interdisciplinary Literary Studies*, *19*(1), 17–47. 10.5325/intelitestud.19.1.0017

Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments*, *21*(4), 373–387. 10.1162/PRES_a_00124

Kool, H. (2016). The ethics of immersive journalism: A rhetorical analysis of news storytelling with virtual reality technology. *Intersect: The Stanford Journal of Science, Technology, and Society*, *9*(3).

Lee, L. H., Braud, T., Zhou, P., Wang, L., Xu, D., Lin, Z., & Hui, P. (2021). *All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda*. arXiv:2110.05352

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: Manipulating bodily self-consciousness. *Science*, *317*(5841), 1096–1099. 10.1126/science.1143439

Li, Y., Ch'ng, E., Cobb, S., & See, S. (2019). Presence and communication in hybrid virtual and augmented reality environments. *Presence: Virtual and Augmented Reality*, *28*, 29–52. 10.1162/pres_a_00340

Lok, B., Naik, S., Whitton, M., & Brooks, F. P. (2003). Effects of handling real objects and self-avatar fidelity on cognitive task performance and sense of presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, *12*(6), 615–628. 10.1162/105474603322955914

Longo, M. R., Schüür, F., Kammers, M. P. M., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition*, *107*(3), 978–998. 10.1016/j.cognition.2007.12.004

Masson, M. E. (2011). A tutorial on a practical Bayesian alternative to null-hypothesis significance testing. *Behavior Research Methods*, *43*, 679–690. 10.3758/s13428-010-0049-5

O'Meara, J., & Szita, K. (2021). AR cinema: Visual storytelling and embodied experiences with augmented reality filters and backgrounds. *Presence: Virtual and Augmented Reality*, *30*, 99–123. 10.1162/PRES_a_00376

Osiurak, F., Jarry, C., Allain, P., Aubin, G., Etcharry-Bouyx, F., Richard, I., & Le Gall, D. (2009). Unusual use of objects after unilateral brain damage. The technical reasoning model. *Cortex*, *45*(6), 769–783. 10.1016/j.cortex.2008.06.013

Petkova, V. I., & Ehrsson, H. H. (2008). If I were you: Perceptual illusion of body swapping. *PLOS ONE*, *3*(12), e3832. 10.1371/journal.pone.0003832

Repetto, C., Germagnoli S., Triberti, S., & Riva, G. (2018). Learning into the wild: A protocol for the use of 360° video for foreign language learning. In *International Symposium on Pervasive Computing Paradigms for Mental Health*, pp. 56–63.

Riva, G., Raspelli, S., Algeri, D., Pallavicini, F., Gorini, A., Wiederhold, B. K., & Gaggioli, A. (2010). Interreality in practice: Bridging virtual and real worlds in the treatment of posttraumatic stress disorders. *Cyberpsychology, Behavior, and Social Networking*, *13*(1), 55–65. 10.1089/cyber.2009.0320

Riva, G., & Wiederhold, B. K. (2022). What the metaverse is (really) and why we need to know about it. *CyberPsychology, Social Networking, and Behavior*, *25*(6), 355–359. 10.1089/cyber.2022.0124, PubMed: 35696299

Sait, M. S. M. Y., Sargunam, S. P., Han, D. T., & Ragan, E. D. (2018). Physical hand interaction for controlling multiple virtual objects in virtual reality. *Proceedings of the 3rd International Workshop on Interactive and Spatial Computing*, pp. 64–74.

Sansoni, M., Bartolotta, S., Gaggioli, A., & Riva, G. (2022). Can you empathize with me? Development of a 360° video-training to enhance residents' empathic abilities. In *2022 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering*, pp. 211–216.

Sciulli, I., Ottoboni, G., & Tessari, A. (2018). Agire su oggetti inusuali: quando funzionalità e struttura si confrontano. *Giornale Italiano Di Psicologia*, *45*(2), 419–425.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, *6*(6), 603–616.

Steffen, J. H., Gaskin, J. E., Meservy, T. O., Jenkins, J. L., & Wolman, I. (2019). Framework of affordances for virtual reality and augmented reality. *Journal of Management Information Systems*, *36*(3), 683–729. 10.1080/07421222.2019.1628877

Suh, A., & Prophet, J. (2018). The state of immersive technology research: A literature analysis. *Computers in Human Behavior*, *86*, 77–90. 10.1016/j.chb.2018.04.019

Ventura, S., Cardenas, G., Miragall, M., Riva, G., & Baños, R. (2021). How does it feel to be a woman victim of sexual harassment? The effect of 360°-video-based virtual reality on empathy and related variables. *Cyberpsychology, Behavior, and Social Networking*, *24*(4), 258–266. 10.1089/cyber.2020.0209

Ventura, S., Miragall, M., Cardenas, G., & Baños, R. M. (2022). Predictors of the sense of embodiment of a female victim of sexual harassment in a male sample through 360-degree video-based virtual reality. *Frontiers in Human Neuroscience*, *16*, 845508. 10.3389/fnhum.2022.845508

Ventura, S., Cebolla, A., Latorre, J., Escrivá-Martínez, T., Llorens, R., & Baños, R. (2022). The benchmark framework and exploratory study to investigate the feasibility of 360-degree video-based virtual reality to induce a full body illusion. *Virtual Reality*, *26*(1), 323–332. 10.1007/s10055-021-00567-6